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VANADIUM

By Henry E. Hilliard

1989

U.S. DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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VANADIUM

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COVER PHOTO:
Ferrovanadium and aluminum-vanadium master alloys are prepared by the thermit reaction in which vanadium pentoxide and iron oxides are coreduced by aluminum granules in a magnesia lined steel vessel or in a water cooled crucible. This photograph shows the thermit mix about to be ignited in a water cooled copper furnace. (Photo is courtesy of Reading Alloys, Inc.)

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VANADIUM

By Henry E. Hilliard

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The year 1988 proved to be a boom year for vanadium producers as tight supply and strong demand by the steel industry and other consumers pushed up the price of vanadium compounds. The U.S. steel industry, which accounted for about 85% of domestic consumption, recorded its highest shipments since 1980's. By the end of 1989, vanadium's fortunes had turned full circle as the market witnessed prices headed for levels lower than at any time since the early 1980s. Price surges in the fourth quarter of 1988 and the first part of 1989 produced the usual results, a significant increase in production and prices followed by a rise in inventories and a consequent slump in prices. Fourth quarter 1988 vanadium pentoxide (V_2O_5) prices of about $3.50 per pound held through the second quarter 1989. Then, demand for ferrovanadium (FeV) by the steel industry and aluminum-vanadium (Al-V) master alloys by the aerospace industry increased sharply. At the same time, operating problems developed in some producer units, causing an apparent shortage and forcing some consumers to buy V_2O_5 and downstream vanadium products from alternate sources at higher prices. Producers of tool and other specialty steels were especially hard hit as the price for V_2O_5 soared to more than $7.00 per pound. As prices continued to rise, consumers began to build inventories in anticipation of even higher prices and tighter supplies expected in the third quarter. Some consumers began to substitute other materials for vanadium. By fourth quarter 1989, it was clear that consumer inventories were excessive and, as producers added new capacity, meeting demand posed no problem. Having built up large stocks, consumers deferred making new purchases while they reduced their inventories. Predictably, prices for V_2O_5 and downstream vanadium products began to fall. First quarter 1990 producer prices for V_2O_5 were expected to fall to about $2.50 per pound. Spot market prices were expected to fall even lower to about $2.30 per pound.

U.S. reported consumption of vanadium was 5,117 tons, a 4% decrease from 1988 consumption.

LEGISLATION AND GOVERNMENT PROGRAMS

On January 1, 1989, the United States and Canada implemented the United States-Canadian Free Trade Agreement (FTA). The objective of the agreement was to eliminate barriers to trade, facilitate conditions of fair competition, liberalize conditions for investment, establish

TABLE 1

SALIENT VANADIUM STATISTICS

(Short tons of contained vanadium unless otherwise specified)

	1985	1986	1987	1988[p]	1989[e]
United States:					
Production:					
Ore and concentrate:					
Recoverable vanadium[1]	W	W	W	W	W
Value thousands	W	W	W	W	W
Vanadium oxide recovered from ore[2]	W	W	W	W	W
Vanadium recovered from petroleum residue[3]	2,695	2,330	2,508	3,252	2,633
Consumption	4,883	4,308	4,653	5,329	5,117
Exports:					
Ferrovanadium (gross weight)	453	513	436	629	544
Ore and concentrate	3	86	—	—	—
Vanadium pentoxide anhydride (gross weight)	1,527	1,544	1,461	1,220	4,124
Other compounds (gross weight)	322	343	479	978	1,709
Imports (general):					
Ferrovanadium (gross weight)	977	747	422	148	716
Ore, slag, ash and residues	303	2,013	2,264	3,986	3,484
Vanadium pentoxide, anhydride	63	443	357	421	148
World: Production from ore, concentrate, slag[4]	33,299	32,530	31,315	33,660	33,800

[e] Estimated. [p] Preliminary. W Withheld to avoid disclosing company proprietary data.

[1] Recoverarable vanadium contained in uranium and vanadium ores and concentrates received at mills, plus vanadium recoverd from ferrophosphorus derived from domestic phosphate rock.

[2] Produced directly from all domestic ores and ferrophosphorus slag; includes metavandates.

[3] Includes vanadium recovered from fly ash, residues, and spent catalysts.

[4] Excludes U.S. production.

procedures for the resolution of disputes, and lay the foundation for further bilateral and multilateral cooperation. The new agreement contained rules and safeguards designed to ensure that minerals, metals, and material products that originate or are produced in either country have equal access to both markets.

Before enactment of the FTA, about 70% of the goods that crossed the United States-Canadian border were free of duty. The remaining 30% will have their duty removed in one of three ways: (1) duty elimination as of January 1, 1989, (2) duty elimination in five equal steps by January 1, 1993, and (4) duty elimination in ten equal steps by January 1, 1998. Rates of duty, effective with respect to goods originating in the territory of Canada and entered on or after January 1, 1989 through January 1, 1993 are shown in the following table:

HTS Subheading	January 1, 1989	January 1, 1990	January 1, 1991	January 1, 1992	January 1, 1993
7202.92.00	3.3%	2.5%	1.6%	.8%	Free.
2850.00.20	12.8%	9.6%	6.4%	3.2%	Free.
2841.90.10	8.9%	6.7%	4.4%	2.2%	Free.
2825.30.00	12.8%	9.6%	6.4%	3.2%	Free.
8112.40.60	2.4%	1.8%	1.2%	.6%	Free.
2841.90.10	8.9%	6.7%	4.4%	2.2%	Free.

It should be noted that the FTA had no effect on the tariffs of either country with third countries.

On August 23, 1988, Congress enacted the Omnibus Trade and Competitiveness Act (Public Law 100–418). The stated objective of the act was to enhance the competitiveness of the Nation's industries and to improve the management of U.S. trade strategy. The Act also included provisions modifying U.S. customs laws and tariff schedules. Subtitle B of the Act required that all tariff schedules after January 1, 1989, conform to nomenclature of the internationally established Harmonized Tariff System (HTS), an international system for classifying products for tariff purposes that had already been adopted by most U.S. trading partners. The new law restructured the old U.S. import-export classification system. The new schedule B classification was based on the organizational framework of the Tariff Schedule of the United States Annotated (TSUSA). That means that equivalent import and export items are assigned the same 10-digit classification code.

On July 11, 1989, the U.S. House of Representatives passed House Bill (H.R. 491) calling for a 3-year mining research initiative aimed at reducing the U.S. dependency on the Republic of South Africa and the U.S.S.R. for strategic and critical minerals. During the 3-year period, the Bureau of Mines would be charged with examining new extractive technologies to recover from domestic deposits such strategic minerals as chromium, manganese, platinum group metals, vanadium and several other metals. If the bill were to become law, it would cost the government $5 million the first year, $10 million the second, and $15 million the third year. Most studies would be completed by 1992.

In July 1989 the Senate passed legislation that would establish a Government-owned U.S. enrichment corporation and provide some relief for the ailing domestic uranium-vanadium mining and milling industry. The new corporation would operate as a private company and presumably be more competitive. The Treasury Department would own all of the stock and collect dividends, if any, generated by the $1.5-billion-a-year enterprise. A companion bill (H.R. 2480) was introduced in the House on May 24, 1989. Both bills (Senate bill 83 and H.R. 2480) were referred to several committees where their disposition was uncertain. H.R. 491 also faced an uncertain future because the Administration and the Bureau of Mines have stated that its provisions would duplicate efforts already underway.

STRATEGIC CONSIDERATIONS

Vanadium is classified as a strategic and critical material because of the significant import dependence of the United States for its vanadium supply and because of essential use of vanadium in equipment for defense, energy, and transportation.

The industrialized countries of the Western World are highly dependent on imports of vanadium pentoxide and vanadium-bearing slag from the Republic of South Africa, which was the world's largest producer of vanadium in 1989, accounting for about 60% of the vanadium produced by market economy countries. Between 1983 and 1988, 44% of U.S. vanadium imports came directly from the Republic of South Africa. Additional material was processed in Western Europe and then imported to the United States as FeV or V_2O_5. The European Community (EC) and Japan were more heavily dependent on South African imports than the United States. In 1988, for example, 60% of the pentoxide consumed by Japan came from the Republic of South Africa. Any extended cutback in supplies from the Republic of South Africa would seriously upset the balance between supply and demand in the market economy countries. Sizable, near-term deficits could only be offset by material from China or the U.S.S.R.

Stockpile

The National Defense Stockpile (NDS) had a 1989 goal of 7,700 tons of vanadium contained in V_2O_5 and 1,000 tons in FeV. Actual yearend stockpile inventories were only 721 tons of vanadium as V_2O_5. The 1989 fiscal year Defense Authorization Act required the Department of Defense to outline plans for at least $20 million in upgrading projects. The Department responded by submitting to Congress an ambitious $30 million plan to upgrade vanadium pentoxide and other materials in the NDS. To justify the planned upgrading program, Defense stated that, although the need for some traditional stockpile materials remains substantial, current and projected military strategies and high-technology weapons systems would require more of the advanced and upgraded forms of industrial materials and less of the conventional materials and unprocessed mineral ores. In August 1989, the Defense Logistics Agency (DLA) issued its upgrading solicitation of about 1,300 tons of Grade-A

TABLE 2

STOCKPILE STATUS, DECEMBER 31, 1989

(Short tons of contained vanadium)

Material	Goal	Inventory
Vanadium pentoxide	7,700	721
Ferrovanadium	1,000	—

V_2O_5. The solicitation was withdrawn a few weeks later, but was expected to be reissued in the second or third quarter of 1990.

ISSUES

Before 1984–85, more than one-half of the vanadium mined in the United States was recovered as a coproduct with uranium from sandstone mined on the Colorado Plateau. Companies recovering vanadium from uranium ores were hurt by the downturn in nuclear power plant construction in the aftermath of the Three Mile Island nuclear reactor accident and the subsequent reduced demand for enriched uranium. Worldwide recession, high interest rates, and the cancellation of power-plant construction in the United States caused the Nuclear Exchange Corp. (Nuexco) exchange value of uranium oxide (U_3O_8) to plummet from $40.75 per pound in early 1980 to less than $10.00 per pound in 1989. The exchange value is Nuexco's judgment of the price at which transactions for significant quantities of uranium concentrates could be concluded on a specified date. Value is based on bids to buy and offers to sell, as well as recently completed and pending transactions.

A direct result of the price decrease was mill closing and decommissioning, personnel cutbacks, and cancelled development and expansion plans. This unstable situation had the potential for creating a much higher degree of dependence by the United States on South African and Chinese imports. However, some of the slack was taken up by increased recovery from petroleum residues. Recovery of vanadium from this source increased during the 1973 Arab oil embargo. Increased demand for petroleum caused refiners to process crude oils with high-sulfur and -metal content. The trend toward heavier, sour crude and a tightening of sulfur restrictions on fuel products led to the development of the "Flexicoking" process, which concentrated 99% of the metals in the feed in a 2% solid purge from the system. This material has become an important source of vanadium, and in some instances, molybdenum and nickel. At the same time, the combustion of increasingly metalliferous fuel oils at power plants created a second source of feed materials in the form of fly ash and boiler scale. During this period the author performed chemical analyses on some boiler scales that contained as much as 35 weight percent (wt %) V_2O_5. More than 30% of the V_2O_5 produced in the United States is now being recovered from refinery residues, fly ash, boiler scale, and spent catalysts. In 1989, 2,600 tons of vanadium was recovered as oxides from these mostly imported petroliferous materials. This source of vanadium may also dry up as clean air standards lead to a tightening of sulfur restrictions on fuel oil products leading to less production of vanadium containing residues. Gradual depletion of Colorado Plateau vanadiferous uranium ores that have been the principal source of domestic vanadium and the expected reduction of available petroleum residues will require the development of alternative sources to maintain domestic self-sufficiency in this strategic mineral.

PRODUCTION

Vanadium is often considered to be an uncommon element, but actually its abundance in the earth's crust is comparable with or greater than that of nickel, zinc, and copper. Although there is a plentiful supply of vanadium, it is one of the most expensive elements to recover. In most cases, whether vanadium occurs as a primary ore, co-ore, or in petroleum, the vanadium content of the material usually runs 1.5% V_2O_5 or less. V_2O_5 is the principal starting material for the production of all vanadium compounds. Therefore, when one speaks of vanadium production or the supply side of the industry, only those involved in the production of V_2O_5 should be included. U.S. vanadium pentoxide producers are shown in the following table:

Producer	Plant location	Capacity (short tons pentoxide per year)
AMAX Metals Recovery Corp. (a subsidiary of AMAX Inc.)	Braithwaithe, LA	2,000
Gulf Chemical & Metallurgical Corp.	Freeport, TX	1,500
Kerr McGee Chemical Corp.	Soda Springs, ID	2,200
UMETCO Minerals Corp.	Blanding, UT	7,500
U.S. Vanadium Corp. (a subsidiary of Stratcor)	Hot Springs, AR	7,500

In January, Atlas Minerals announced the sale of all its Utah and Colorado uranium and vanadium properties and related mining equipment. The sale finalized an earlier decision by Atlas to withdraw completely from the uranium-vanadium business. The company was also reviewing an engineering study with the Nuclear Regulatory Commission (NRC) that would allow Atlas to finalize the decommissioning and reclamation plan for its Moab, UT, uranium-vanadium operations. The Moab mill had the capacity to produce about 2,200 tons per year of V_2O_5.

In February, Strategic Minerals Corp. (Stratcor), based in Danbury, CT, announced plans to renovate and expand its multimillion dollar ferrovanadium facility at Niagara Falls, NY. The expansion included new furnace operations that allowed Stratcor to increase its output of Nitrovan by about 50%. Nitrovan, a proprietary compound containing vanadium and nitrogen, can be used by steelmakers for strengthening steel in place of standard FeV. The company also announced plans to double its capacity for the production of vanadium tetrachloride to help meet growing demand for vanadium catalysts.

The Niagara Falls plant depended on Stratcor's Hot Springs, AR, mill for supplies of V_2O_5 that it converted to FeV and other vanadium chemicals. The mill, operated by U.S. Vanadium Corp., a subsidiary of Stratcor, produced V_2O_5 from a variety of raw materials, including vanadium-bearing slag and petroleum refinery residues. Delays in obtaining raw materials and

difficulties with reactivating some mothballed equipment kept V_2O_5 supplies from Hot Springs lower than expected. This caused temporary cutbacks on expected shipments of FeV to customers. The problems at Hot Springs were eventually cleared, ensuring an adequate supply of V_2O_5 for the production of FeV and the expanded Nitrovan facilities.

AMAX Metals Recovery Corp. operated a spent catalyst treatment plant in Braithwaite, LA, that recovered vanadium and other metals from petroleum refinery catalyst. In 1989, the plant produced, in addition to more than 1,000 tons V_2O_5, 90 tons of molybdenum trisulfide and 10 tons of cobalt concentrate. The company planned to expand its product base to include extracting chromite from waste acid solutions that were used to etch aluminum and vanadium from fly ash. No timeframe was given for completion of the expansion. The company also planned to recover vanadium from waste Stretford process solutions that were used to scrub hydrogen sulfide from gas streams.

Production of V_2O_5 increased sharply at Umetco Minerals Corp.'s Blanding, UT, mill. Production averaged about 330 tons per month. Total production in 1988 was only about 600 tons. A major portion of the 1989 production represented toll work. The mill, which is jointly owned with Energy Fuels Nuclear Corp., produced V_2O_5 at the rate of about 500 tons per month during the first quarter. The mill was then shut down in the second quarter for routine maintenance and improvements to the vanadium extraction process. Production resumed in September. Output of vanadium increased in part because demand increased and prices rose sharply, but also because the Blanding Mill was the only mill still in operating condition capable of recovering vanadium from uranium-vanadium ores.

CONSUMPTION AND USES

Reported consumption of vanadium was a little more than 5,000 tons of contained vanadium or about 4% less than in 1988. Part of this reduction was attributed to reduced demand by the steel industry, in which production was down by about 2% from that of 1988. Another part could be attributed to substitution of other materials or treatments for vanadium, although an uncertain amount could be assigned to reduced reporting by consumers to Bureau of Mines surveys.

About 85% of all vanadium consumed is accounted for by use in the steel industry as an alloying agent. Another 10% is used in aerospace titanium alloys with the remainder in chemical and catalyst preparations. Vanadium is an essential but not totally indispensable alloying metal. Often the addition of micro amounts can provide considerable improvement in performance without further processing or a significant increase in cost over standard grades. When alloyed with steel, vanadium combines with carbon or nitrogen or both, then precipitates, causing an increase in strength and toughness. In addition, vanadium provides such added benefits as better weldability and heat resistance. Various metals, such as columbium, manganese, molybdenum, titanium, and tungsten, are interchangeable with vanadium, but so far there are no substitutes for vanadium in the all-important aerospace titanium alloys that are used in jet engine mountings and wing structures. High-purity vanadium compounds are used as catalysts in the production of sulfuric acid, maleic anhydride, and in pollution control technology where it is necessary to remove hydrogen sulfide gas from flu gases (Stretford Process). In only a few chemical applications can platinum and nickel replace vanadium catalyst.

STOCKS

Reported consumers' and producers' stocks of vanadium oxides, metal, alloys, and chemicals totaled 1,736 tons contained vanadium at yearend compared with 1,396 at yearend 1988.

FOREIGN TRADE

While overall exports of vanadium products were slightly lower than in 1988, V_2O_5 exports were up sharply in 1989. Canada, Brazil, the Republic of Korea, and Mexico were the leading importers of U.S. materials. Most countries imported V_2O_5 almost exclusively. Austria, Canada, and the Republic of Korea also imported substantial quantities of FeV. Exports of V_2O_5 totaled 2,310 tons, almost double 1988 exports. The average declared value of the pentoxide was $7.62 per pound of contained V. Exports of FeV totaled 544 tons gross weight, down from 909 tons in 1988. The average declared value of the FeV was $18.70 per pound of contained V.

Imports for consumption of vanadium raw materials and down-stream vanadium compounds increased over 1988 imports. FeV imports totaled 716 tons gross weight, up from 147 tons in 1988 and 422 tons in 1987. The imported FeV averaged 81% vanadium with a mean custom value of $12.34 per pound of contained V. Canada was the largest source of FeV with shipments of 163 tons, followed by the Federal Republic of Germany, 128 tons, and Austria, 109 tons. V_2O_5 imports totaled 102 tons of contained V, down from 241 tons in 1988; the average declared value was $9.39 per pound of contained V. Imports of vanadium-bearing slag and residues totaled more than 6,000 tons of contained V. About 44% of these imports were from the Republic South Africa in the form of vanadium bearing iron-slag. Another 28% was vanadium-bearing steel slag from Chile. The remaining 28% consisted of an assortment of petroleum residues, spent catalyst, and fly ash.

WORLD REVIEW

Industry Structure

Vanadium was traded on the world market in vanadium-bearing slag, petroleum residues, technical grade V_2O_5, and FeV. The Republic of South Africa was the largest producer, providing more than 60% of the Western World's market. Most of the Republic of South Africa's exports of vanadium were in vanadium-bearing iron slag. Japan and Western Europe were the chief importers of this material. While the United States imported slag from the Republic of South Africa, it also imported slag, fly ash, petroleum residues, and spent catalyst from many sources. The large importers of vanadium raw materials, for example,

TABLE 3

VANADIUM SUPPLY-DEMAND RELATIONSHIPS AND PRICES

(Short tons vanadium content)

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989[e]
World production from ores, slag, and concentrates											
Recovered basis:											
United States	5,758	5,506	6,368	4,867	2,433	2,620	W	W	W	W	W
World, other	31,791	33,475	33,652	31,800	27,916	32,675	33,2993	2,5303	1,3153	3,6603	3,800
Total	37,549	38,981	40,020	36,667	30,349	35,295	33,299	32,530	31,315	33,660	33,800
Component and distribution of U.S. supply											
Components of U.S. supply:											
Primary production, domestic mines	5,758	5,506	6,368	4,867	2,433	2,620	W	W	W	W	W
Imports, ferrovanadium	517	263	984	670	681	1,171	779	605	342	119	441
Imports, ores, slag, and residues	2,442	1,786	2,435	1,112	58	633	303	2,013	2,264	3,986	3,484
Imports, vanadium pentoxide	907	856	334	119	377	149	11	248	229	421	102
Imports, other	1,519	1,304	1,400	1,090	1,078	2,210	193	201	94	122	397
Shipments of Government stockpile excesses	—	—	--	—	—	-68	-112	—	—	—	—
Industry stocks, January 1	11,374	11,089	11,155	12,502	12,564	12,102	10,486	1,842	2,057	1,396	612
Total U.S. supply	22,517	20,804	22,676	20,360	17,191	18,817	11,657	4,909	4,986	6,044	5,036
Distribution of U.S. supply:											
Industry stocks, December 31	11,089	11,155	12,502	12,564	11,748	10,486	W	W	W	W	W
Exports, ore	101	46	56	57	59	12	3	86	—	—	—
Exports, ferrovanadium	616	562	304	229	542	328	318	415	348	503	434
Exports, vanadium pentoxide	353	406	194	886	1,484	2,079	855	192	134	683	2,310
Exports, other	190	114	36	217	57	183	193	343	479	548	957
Industrial demand	10,168	8,521	9,584	6,406	3,301	5,729	W	W	W	W	W
U.S. demand pattern (SIC)											
Building and heavy construction	1,170	950	1,100	920	490	740	W	W	W	W	W
Chemicals	460	310	220	140	50	130	W	W	W	W	W
Machinery, construction machinery and industrial equipment	1,330	1,210	1,390	790	390	730	W	W	W	W	W
Machinery, metalworking machinery and tools	1,740	960	880	540	450	750	W	W	W	W	W
Mining, quarrying, and lumbering	190	150	160	90	60	110	W	W	W	W	W
Oil and gas industries	800	1,170	1,730	860	100	290	W	W	W	W	W
Transportation	3,550	2,960	3,200	2,260	1,350	2,370	W	W	W	W	W
Other	928	811	904	806	411	609	W	W	W	W	W
Total U.S. primary demand	10,168	8,521	9,584	6,406	3,301	5,729	W	W	W	W	W

See footnotes at end of table.

TABLE 3—Continued

VANADIUM SUPPLY-DEMAND RELATIONSHIPS AND PRICES

(Short tons vanadium content)

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989[e]
	Prices										
Average annual, actual (dollars per pound vanadium content)	6.05	6.33	6.28	6.25	6.25	6.25	6.25	6.25	6.2	8.95	7.50
Average annual, based on constant 1989 dollars (dollars per pound)	9.72	9.32	8.43	7.89	7.89	7.89	7.89	7.89	7.89	9.31	7.50

[e] Estimated. W Withheld to avoid disclosing company proprietary data.

slag, were the chief exporters of V_2O_5, FeV, and other downstream vanadium products. This trade was dominated by a few large West European converters who competed not only within Europe, but also exported to many smaller consumers outside of Europe. Reliable statistics from the U.S.S.R. were not available but it is believed to be second only to the Republic of South Africa in vanadium production. All Soviet trade was thought to be with other Eastern Bloc countries.

Capacity

The data in table 7 reflect rated capacity for mills producing vanadium oxides as of December 31, 1989. Included in this data is the capacity to produce vanadium-bearing iron slag and petroleum coke. Rated capacity is defined as the maximum quantity of product that can be produced on a normally long-term operating rate, based on the physical equipment of the plant and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that can be brought back into production within a short period with minimum capital expenditure.

Australia

Western Australia has large deposits of magnetite ores containing vanadium and titanium. The deposit, consisting of a large magnetite-rich intrusive rock, was analyzed more than 20 years ago and found to contain only about 0.32% V_2O_5. This deposit was ignored for many years because of the low price of vanadium. As the price of vanadium climbed in 1987 and 1988, Precious Metals Australia (PMA) reevaluated the deposit at its wholly owned Wagoo Hills project in the Murchison District of Western Australia. Surprisingly, the titanium and vanadium mineralization was found to grade up to 0.93% V_2O_5 and 12% titanium dioxide (TiO_2). The deposit lies within a distinct and reasonably well defined geologic structure known as Shepard's Discordant Zone (SDZ) that extends along a 10 mile strike within PMA's property. The latest sampling was carried out across the SDZ in areas of abundant titanomagnetite surface rock with samples

TABLE 4

PRODUCERS OF VANADIUM ALLOYS OR METAL IN THE UNITED STATES IN 1989

Producer	Plant location	Products[1]
Affiliated Metals and Minerals Inc.	Newcastle, PA	FeV.
KB Alloys Inc.	Henderson, KY	VAl, ZrVAl.
Do.	Wanatchee, WA	Do.
Reading Alloys Inc.	Robesonia, PA	FeV, VAl, V.
Shieldalloy Metallurgical Corp.	Cambridge, OH	FeV, Ferovan.[2]
Strategic Minerals Corp.	Niagara Falls, NY	FeV, VAl, Nitrovan.[2]
Teledyne Wah Chang Albany	Albany, OR	V, VAl.

[1] FeV, Ferrovanadium; V, vanadium metal: VAl, vanadium-aluminum alloy; ZrVAl, zirconium-vanadium-aluminum alloy.
[2] Registered trademark for proprietary products.

TABLE 5

U.S. CONSUMPTION AND CONSUMER STOCKS OF VANADIUM MATERIALS, BY FORM

(Short tons of contained vanadium)

Form	1988		1989	
	Consumption	Ending stocks	Consumption	Ending stocks
Ferrovanadium[1]	4,497	631	4,197	446
Oxide	18	17	21	10
Ammonium metavanadate	W	W	W	W
Other[2]	813	56	898	160
Total[3]	5,329	704	5117	615

W Withheld to avoid disclosing company proprietary data, included with "Other."
[1] Includes other vanadium-iron-carbon alloys, as well as vanadium oxides added directly to steel.
[2] Consists principally of vanadium-aluminum alloy and relatively small quantities of other vanadium alloys and vanadium metal.
[3] Data may not add to totals shown because of independent rounding.

TABLE 6

U.S. CONSUMPTION OF VANADIUM IN 1989, BY END USE

(Short tons of contained vanadium)

End use	Quantity
Steel:	
Carbon	1,216
Stainless and heat-resisting	106
Full alloy	990
High-strength low-alloy	1,350
Tool	463
Unspecified	W
Total	[1]4,124
Cast irons	20
Superalloys	42
Alloys (excluding steels and superalloys):	
Cutting and wear-resistant materials	W
Welding and alloy hard-facing rods and materials	8
Nonferrous alloys	W
Other alloys[1]	816
Chemicals and ceramics:	
Catalysts	10
Other[2]	W
Miscellaneous and unspecified	96
Grand total[3]	5,117

W Withheld to avoid disclosing company proprietary data, included with "Miscellaneous and unspecified."
[1] Includes magnetic alloys.
[2] Includes pigments.
[3] Data do not add to total shown because of independent rounding of converted units.

collected at two- and six-yard intervals. Indications were that the region was likely to contain up to 40 million tons of high iron magnetite ore containing an average of 0.75% V_2O_5 and as much as 12% titanium.[1]

Preliminary metallurgical work suggested that a magnetite concentrate could be produced from grinding and magnetic separation. An $86 million mine development and processing plant was planned to produce about 2,100 tons of V_2O_5 per year.

The deposit ranks as a potentially significant iron ore discovery, but given the long distance from the nearest port, it would be more economic to extract the vanadium and titanium and discard the iron as waste.

Canada

Agra Industries Ltd. of Saskatoon, Saskatchewan, teamed with Renzy Mines Ltd. and Fairfax Financial Holdings Ltd. of Toronto, Ontario, to construct a vanadium pentoxide facility at Fort McMurry, Alberta. The plant, which cost $14 million, was designed to extract about 2.5 million pounds per year of V_2O_5 from waste fly ash produced by the Suncor Inc. oil sands plant.[2] The Athabasca oil sands, located in northern Alberta, was well known for its wealth of oil, and a number of projects have been launched to extract it. Less known was the fact that a number of other elements, including vanadium, were also found in the oil sands. In fact, the Athabasca oil sands may prove to be the largest reserves of vanadium in North America.

Vanadium appeared in the oil sands only in trace concentrations, making economic recovery impossible. However, when the material was treated to recover heavy oil, vanadium was concentrated in a stream of waste petroleum coke. Subsequent burning of this coke in the plant's power steamboiler produced a fly ash consisting mainly of carbon and V_2O_5 concentrations ranging from 2% to 5%. The Alberta Suncor and Syncrude refineries produced about 43,000 tons of fly ash per year. To secure access to the vanadium-rich flyash, Carbovan Inc., obtained an exclusive long-term agreement to purchase the waste flyash produced by Suncor. Carbovan also had access to flyash that had been stockpiled by Suncor over the years. In addition to these supplies of raw materials, Carbovan obtained agreements to purchase vanadium-rich spent catalyst discharged by various petroleum processors in Canada.

Initial concepts of Carbovan's recovery process were developed by Renzy Mines in 1972. Between 1972 and 1985, Renzy spent about $500,000 to further develop and improve the process. In mid-1985, Renzy and Agra entered into an agreement to conduct further research and development of the Renzy process. Under terms of the agreement, Agra provided financial, management, and engineering support to the research. After expenditures of $1.5 million and 3 years of research and development, an economical process was developed. The process utilized a hydrometallurgical flotation technique to remove carbon from the fly ash. The carbon free ash fraction was next treated with a high-temperature alkaline leach and pulse column solvent extraction circuits to extract vanadium.

TABLE 7

WORLD VANADIUM PENTOXIDE ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989[1]

(Short tons of vanadium content)

Country	Rated capacity[2]
Australia	1,600
Brazil	—
Canada	850
Chile	2,500
China	9,000
South Africa, Republic of	30,000
U.S.S.R.	10,500
United States	12,100
Venezuela	2,700
Other market economy countries	600
Total	69,850

[1] Includes capacity to produce vanadiferous iron slag and vanadium-bearing petrolem residues.
[2] Includes capacity of operating plants, as well as plants on standby basis.

Chile

Compañía Minera del Pacífico (CMP), Chile's sole iron ore and pellet producer, examined the possibility of producing and exporting vanadium from its El Romeral Mine where the iron ore has a grade of 0.5% to 0.7% vanadium.[3] A three-stage laboratory, pilot plant, and economic study was completed, and the company began an engineering study to determine the type of equipment required. Based on previous findings, Pacífico decided to use a roast-leach process to produce vanadium as a byproduct from the concentration of 1,500 tons per day of iron ore from El Romeral. The company hoped to earn about $25 million per year from vanadium exports.

China

China's production of vanadium-bearing iron slag was 93,750 tons in 1989.[4] Approximately 80% of the output was from the Panzhihua Steel Works in Sichuan Province. Slag from this plant averaged 14% V_2O_5, which placed China's vanadium production at about 7,400 tons of contained vanadium; only the Republic of South Africa and the U.S.S.R. produced more.

Vanadium production was down

TABLE 8

U.S. IMPORT DUTIES, JANUARY 1, 1989

Tariff item[1]	HTS Number	Most Favored Nation (MFN)	Non-Most Favored Nation
Ores and concentrates	2615.90.6090	Free.	Free.
Slag	2619.00.9030	Free.	Free.
Ash and residues	2620.50.0000	Free.	Free.
Vanadium pentoxide anhydride	2825.30.0010	16.0% ad val.	40% ad val.
Vanadium oxides and hydroxides, other	2825.30.0050	16.0% ad val.	40% ad val.
Vanadates	2841.90.1000	11.2% ad val.	40% ad val.
Ferrovanadium	7202.92.0000	4.2% ad val.	25% ad val.
Aluminum-vanadium master alloys	7601.20.9030	Free.	10.5% ad val.
Waste and scrap	8112.40.3000	Free.	Free.

[1] Specific import classes only.

about 4% from 1988 production because of a reduction in the operating level at Panzhihua. Exports were also lower than in previous years, mostly because of increased internal demand.

South Africa, Republic of

The Republic of South Africa, the world's largest producer of vanadium, was projected to increase its capacity by 28% over 1988's capacity and produce about 40% more of the alloying element by 1990. In 1988, production of vanadium marked an alltime high of 63 million pounds of V_2O_5, more than 10% above 1987 production. Production figures for 1989 were not available, but were expected to be about the same, or slightly less, than 1988 production. Sales of vanadium totaled 28,900 tons V_2O_5, of which 653 tons was used internally and 28,300 tons was exported.[5]

Most of the planned increase in capacity was from a new facility, which was to obtain its feedstock from reserves of titaniferous magnetite in Bophuthatswana. The project, designed to produce 9,900 tons of V_2O_5 annually, was a co-operative venture between Union Steel Corp. (Usco) and Rhombus Exploration (RhoEx) to exploit a high-grade deposit stretching over a distance of 10.5 miles. Ore reserves were estimated to be sufficient to support production for about 100 years.

The company extracted V_2O_5 by the roast-leach process. While other South African producers used a rotary kiln or a conventional furnace to roast the ore, Usco used a shaft furnace. This furnace reportedly had several advantages: (1) the furnace was fired by South African synthetic oil (Sasol) gas instead of coal, which tends to introduce impurities, (2) direct energy costs were claimed to be up to 5% lower, (3) the vanadium yield was at least 90% compared with around 80% for a rotary kiln, and (4) chemical costs were reduced by about 50% because a rotary kiln requires 7 wt % soda ash compared with 4 wt % for a shaft furnace. Usco anticipated the cost of production of V_2O_5 flake would be in the range of $4,500 to $4,700 per ton. Mechanical commissioning of the beneficiation plant at Rhovan's Mine, which provided the magnetite concentrate, was completed and wet commissioning was scheduled to start in March 1990.[6] Brandeis Goldschmidt Ltd., headquartered in London, acted as sole agent for V_2O_5 produced by Usco.

Highveld Steel & Vanadium Corp., the world's largest vanadium producer, was forced to cut production at its Vantra Plant by two-thirds because of low spot market prices. Production of vanadium in iron slag at the Highveld steel plant was not affected by the cutback. The decision to cut production at Vantra was an attempt by Highveld to stabilize prices at a comfortable level and maintain a balance between supply and demand.

The newest South African V_2O_5 producer, Vansa Vanadium Corp., began production in October 1988. Its operations were supplied by the Kennedy's Vale high-grade ore deposit. The plant, located in Eastern Transvaal, had a design capacity of 3,000 tons per year of V_2O_5. The company reported that, as a result of postcommissioning problems, the plant had been unable to achieve its full design capacity. For most of the fiscal year ending September 30, 1989, the plant operated at just over 60% capacity. The company expected that full production would be achieved during 1990.

Other established producers in the Republic of South Africa are Vametco in Bophuthatswana, owned by Strategic Minerals Corp. of the United States, and Transvaal Alloys, which produced V_2O_5 and other vanadium chemicals. The Republic of South Africa's domestic consumption of vanadium was believed to be about 1% of its total production.

OUTLOOK

Outlook For 1990

Vanadium shipments in 1990 are expected to decline approximately 3% to about 5,500 tons. The decline is expected to be the result of a weakness in a key vanadium consuming sector, steel used for nonresidential construction, without equal offsetting growth in other important markets. Demand for the transportation sector is expected to be adversely affected by lower sales of domestically produced motor vehicles. The appliance industry is likely to buy less steel because of a decline in housing starts. On the bright side, some pickup in demand for aluminum-vanadium alloys can be anticipated from aerospace industries, which are benefiting from increased demand for air transports. Also, increased demand is anticipated from large capital goods industries that are benefiting from increased capital investment and increased exports. Individually, aerospace and capital goods industries are much smaller consumers of vanadium than the other important markets. Vanadium exports are expected to rise moderately.

The likely drawdown of inventories by vanadium consumers through the first and second quarters of 1990 should also have an adverse effect on domestic demand. Consumers are expected to draw down their inventories because they are no longer concerned about difficulties in obtaining vanadium in a timely manner and at a reasonable price. Prices of most products are likely to stabilize.

Nearly every segment of the chemical industry using vanadium catalysts is growing. Strong demand for chemicals

and polymers, for fuel from petroleum, for products that reduce pollution, and for biological materials, is increasing. With few exceptions, most sulfuric acid produced in the world is made by burning sulfur to produce the oxide and then oxidizing the dioxide to the trioxide using V_2O_5 catalyst on a diatomaceous earth carrier. Growth in demand for this type of catalyst is forecast to be slow. Resurging markets for vanadium catalyst in other sectors of the chemical industry are providing new incentives for research and development in vanadium catalysts and in processes that require their use.

Long-Term Prospects

Long-term prospects for this highly cyclical industry depend on a number of factors. Producers will certainly be adversely affected by any future economic downturn. Because of restructuring and downsizing that has occurred in the industry since the last recession, the industry will be better able to cope with a recession than it was in the early 1980's. Traditional forces, such as the demand for motor vehicles and machinery, the level of economic activity, and the use of substitute materials, will continue to be of central importance. The strength of the U.S. dollar and its trade effects will also influence the industry's long-term future.

Fundamental changes over the past 10 years in the industry and in the general economy have all but precluded the possibility of a return to the late 1970's and early 1980's level of vanadium mining activity. There will almost certainly be fewer tons of domestic ore shipped and fewer mine workers by 1995 than there were in 1989. Production of V_2O_5 from fly ash, spent catalyst, and petroleum residues will continue to increase. Given favorable economic conditions, plants using these materials as feed will have higher average sales and be more profitable.

BACKGROUND

Vanadium has been used as an alloying element in steel since 1902, when it was first added to tool steels used for high-speed machining operations. It was found that vanadium prevented grain growth in tungsten-bearing steels and enabled the steels to maintain their hardness at the high temperatures generated in tool steels during high-speed machining. Vanadium is also widely used in high temperature steels used in steam power plants. Chromium-vanadium steels are used for steel pipes and headers and molybdenum-vanadium steels are used for rotors because of the high creep resistance produced by vanadium carbides. An increasing amount of vanadium has been used in the production of high-strength low-alloy (HSLA) steels to provide yield points between 36 and 47 kilograms per square millimeter. The addition of small amounts of vanadium, often less than .1 wt %, to an ordinary carbon steel can significantly increase its strength and improve both its toughness and ductility. HSLA steels with high yield points are attractive for structures such as automobiles, bridges, high-rise buildings, and pipelines where advantage can be taken of the savings in weight produced by the high-yield points. Vanadium is also used extensively to provide elevated temperature strength to certain aerospace titanium alloys, the most common of which is an alloy containing 6 wt % aluminum and 4 wt % vanadium. This alloy is widely used for aircraft engine casings and fans and accounts for about 10% of U.S. vanadium use. Oxides and chlorides of vanadium play important roles as catalysts in the production of sulfuric acid, maleic anhydride, synthetic rubber, and other key intermediate organic chemicals.

Vanadium is found in many parts of the world, but usually in association with other minerals. There are few ores from which vanadium can be economically extracted as a single product. It is therefore often extracted as a byproduct or coproduct in the production of other elements, such as iron, phosphorus, or uranium. Increasing amounts are being recovered from clays, petroleum residues, and spent catalysts. At present projected rates of consumption, world reserves of vanadium should last far beyond the year 2000. The world also has extensive subeconomic resources of vanadium contained in oil sands, carbonaceous shale, and bauxite.

The Republic of South Africa is the world's largest producer of ore and vanadium-bearing slag. Its annual production of more than 17,000 tons is approached only by production in the U.S.S.R. The bulk of U.S.S.R. production is consumed internally or by other Eastern Block countries. Other major producers include the United States, and China. Canada, Japan, and Western Europe are heavily dependent on imports of vanadium slag and pentoxide from the Republic of South Africa. Any disruption of South African supplies could seriously upset the balance between vanadium supply and demand. World demand is forecast to increase by about 2% per year, with total world demand reaching 45,000 tons by the year 2000. World production in 1989, including production from petroliferous materials and spent catalysts, was estimated to be 37,400 tons, of which about 2,600 tons was produced in the United States from petroleum residues and spent catalysts.

Definitions, Grades, and Specifications

The term "ferrovanadium," as used by the Bureau of Mines, includes vanadium-carbon-iron-nitrogen proprietary alloys as well as the conventional forms of ferrovanadium. Some of the more common commercial products are listed in the following table:

Alloy	Composition, weight percent							
	Vanadium	Carbon	Nitrogen	Aluminum	Silicon	Phosphorus	Sulfur	Manganese
50%–60% ferrovanadium	50.0–60.0	0.2 max.	—	2.0 max.	1.0 max.	0.05 max.	0.05 max.	—
70%–80% ferrovanadium	70.0–80.0	—	—	1.0 max.	2.5 max.	.05 max.	.10 max.	—
80% ferrovanadium	77.0–83.0	.5 max.	—	.5 max.	1.25 max.	.05 max.	.05 max	0.5 max.
Proprietary alloys:								
Carvan (Stratcor)	82.0–86.0	10.5–14.5	—	.1 max.	.10 max.	.05 max.	.10 max.	.05 max.
Ferovan (Shieldalloy)	42.0 min.	.85 max.	—	—	7.0 max.	—	—	4.50 max.
Nitrovan (Stratcor)	78.0–82.0	10.0–12.0	6.0 min.	.1 max.	.1 max.	.05 max.	.01 max.	.05 max.

A standard specification for ferrovanadium has been developed by the American Society for Testing Materials (ASTM).[7]

Aluminum-vanadium master alloys contain fixed ratios of vanadium to aluminum and are used in the manufacture of titanium alloys. Amounts of vanadium up to 1 wt % improve the strength of titanium-base alloys and promote their thermal stability in the presence of moderate amounts of aluminum. When amounts greater than 4 wt % are added, the titanium base-alloy can be significantly strengthened by heat treatment. The three most important commercial titanium alloys containing vanadium are Ti-6Al-4V, Ti-6Al-4V-2Sn, and Ti-8Al-1Mo-1V. Ti-6Al-4V alloy presently accounts for more than one-half of the titanium-base alloy market.

Products for Trade and Industry

Vanadium is usually traded on the international market in the form of technical grade V_2O_5 and ferrovanadium. Most world exports of vanadium raw material is in the form of vanadium-bearing iron slag from the Republic of South Africa and China, while U.S. and west European converters are the major importers of these materials. U.S. and west European converters are the major exporters of vanadium oxides, which supply the many small consuming countries, and compete for the major markets for imported pentoxide in Japan and the Republic of Korea. Trade in ferrovanadium is dominated by the major European exporters. A large part of this trade is within Europe but exports are made to many other consuming countries, particularly by the Federal Republic of Germany.

Industry Structure

The vanadium industry has a five-tiered structure with facilities on all six continents. As expected, mines and oil fields form the base of the structure (figure 1). Since 1979, an estimated 83% of world production has come from vanadiferous magnetite (Fe_3O_4). The principal sources of the magnetite ore were China, the Republic of South Africa, and the U.S.S.R. World vanadium production for 1985–1989, is shown in table (12). The other 17% of the vanadium was recovered from diverse petroliferous materials.

The second tier is a set of economically unrelated facilities that include (1) pig iron plants with slag recovery units, (2) elemental phosphorus smelters, and (3) generators of petroleum residues, fly ash, and spent catalysts that contain vanadium either as the active material or as a contaminant.

The third tier consists of acid-leaching plants with solvent extraction circuits, and salt-roasting operations. Technical grade V_2O_5 and NH_4VO_3 are the principal products at this level.

To have an easily marketable product, it is customary at this point to either convert the oxides into an alloy or upgrade their purity to greater than 98.5 wt %. The two traditional alloy products have been the 80 wt % ferrovanadium and 35 wt % aluminum-vanadium master alloy. Variations of five different reduction processes are currently in use throughout the world, with aluminum, carbon, or silicon serving as the reductant. These conversion and upgrading plants, which form the fourth tier of the structure, may be located a considerable distance from the mills and slag plants and frequently blend feed materials to improve recovery.

Of the more than 30 privately owned producers, only 1, the Republic of South Africa's Highveld, operates facilities at all 4 lower levels and can be considered totally integrated. Highveld has plants that process vanadiferous-magnetite ores from the Bushveld Igneous Complex. Two other producers, Shieldalloy Metallurgical Corp. and Stratcor, have extensive operations on the second, third, and fourth tiers. Shieldalloy traditionally uses Highveld slag as its starting material for low vanadium grades of ferrovanadium.

The fifth tier is composed of producers of vanadium specialty alloys, high-purity vanadium metal, primary vanadium chemicals, and vanadium catalysts. Reading Alloys Inc., Akzo Chemical, and Teledyne Wah Chang Albany illustrate the diversity of operations at this level.

Geology-Resources

The crustal abundance of vanadium is estimated to be 100 to 150 parts per million (ppm), about twice that of copper, 10 times that of lead, and almost 100 times that of molybdenum.[8] As a result, trace vanadium mineralization occurs in a wide range of geologic provinces and environments. At the same time, ore deposits of vanadium are rare because much of the vanadium in igneous rocks occurs dispersed in the relatively insoluble trivalent state and is substituting for ferric iron in ferromagnesian silicates, magnetite, ilmenite, and chromite.

Technology

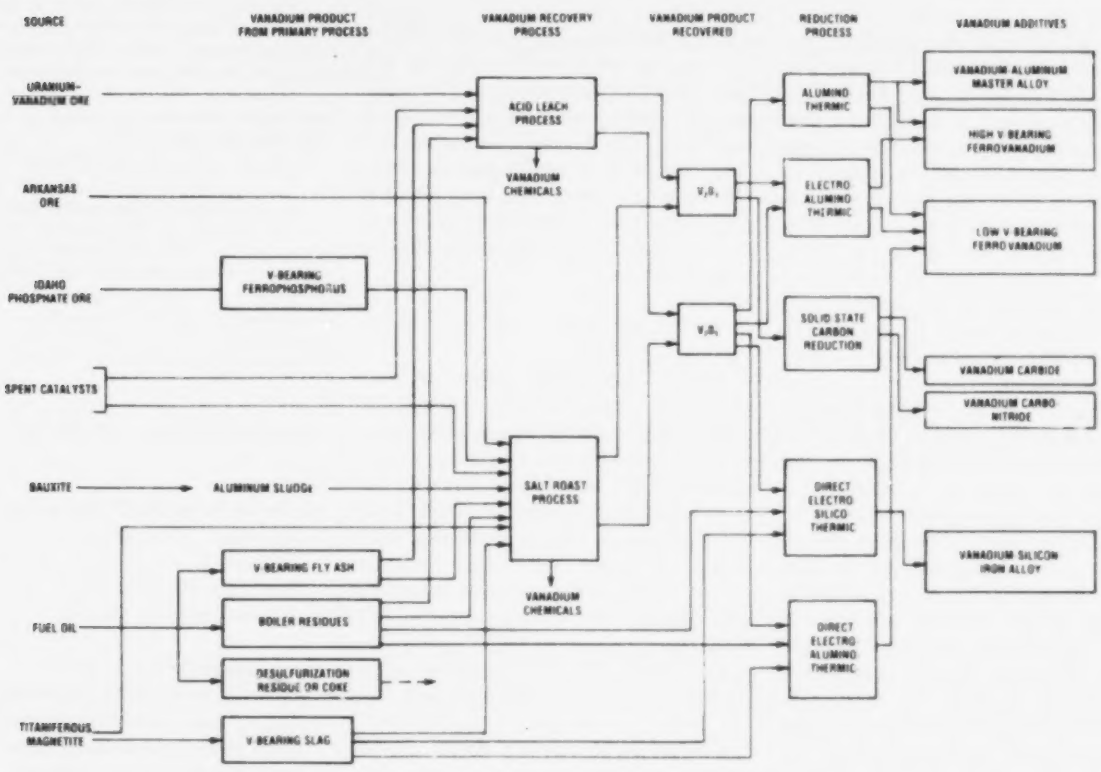
Processing—In the United States, vanadium is recovered as a principal mine product, as a coproduct from carnotite ores, and as a byproduct from ferrophosphorus slag in the production of elemental phosphorus. Increasingly, it is also being recovered from petroleum refinery residues, fly ash, and spent catalysts. In the Republic of South Africa and China, vanadium is recovered as a byproduct of pig iron production from titaniferous magnetite.

The first stage in the processing of vanadium ore is the production of an oxide concentrate. The ore is crushed, ground, screened, and mixed with a sodium salt. This mixture is roasted at about 850 °C to convert the oxides to water-soluble sodium metavanadate. The vanadium is extracted by leaching with water and precipitated at pH 3 as sodium hexavanadate (red cake) by the addition of sulfuric acid. The red cake is fused at 700 °C to yield a dense black product that is sold as technical grade vanadium pentoxide. Technical grade vanadium pentoxide contains a minimum of 86 wt % pentoxide and a maximum 8 wt % sodium oxide. The red cake may be further purified by dissolving it in an aqueous solution of sodium carbonate. Aluminum, iron, and silicate impurities precipitate from solution upon pH adjustment. Ammonium metavanadate is then precipitated by the addition of ammonium chloride. The precipitate is calcined to give a vanadium pentoxide product of greater than 99.8% purity.

Vanadium is extracted as a coproduct with uranium from carnotite by direct leaching of the ore with sulfuric acid. An alternative method is roasting the ore followed by countercurrent leaching with dilute sulfuric acid. In some cases, the first leach may be with a sodium carbonate solution. The uranium and vanadium are then separated from the pregnant liquor by liquid-

FIGURE 1

GENERALIZED FLOWSHEET FOR THE PROCESSING OF VANADIFEROUS RAW MATERIALS



liquid extraction techniques.

In the Republic of South Africa and China, vanadium is concentrated in slag resulting from the production of pig iron from titaniferous magnetite ore. The ore, containing 1.5% to 2.5% vanadium pentoxide, is partially reduced with coal in rotary kilns. The ore is then melted in an enclosed furnace which produces a slag containing most of the titanium and pig iron containing most of the vanadium. After the titanium-bearing slag is removed, the molten pig iron is blown with oxygen to form a slag containing 12 wt % to 24 wt % vanadium pentoxide. The slag is separated from the molten metal and may then be used as a high-grade vanadium raw material in the usual roast-leach process.

Vanadium is added to the steelmaking process as a ferrovanadium alloy, which is produced commercially by the reduction of vanadium pentoxide or vanadium bearing-slag with aluminum, ferrosilicon, or carbon. In the aluminothermic process for preparing ferrovanadium, a mixture of technical grade pentoxide, aluminum, iron scrap, and a flux are charged into an electric furnace and the reaction between aluminum and pentoxide initiated. The reaction is highly exothermic, producing very high temperatures. The temperature can be controlled by adjusting the particle size of the reactants and the feed rate of the charge and by using partially reduced pentoxide or by replacing some of the aluminum by a milder reductant. Ferrovanadium containing up to 80 wt % vanadium can be produced by this method. A process developed by Foot Mineral Co., Cambridge, OH (now Shieldalloy Metallurgical Corp.), has been used to produce tonnage quantities of ferrovanadium. This process involves the reaction of vanadium-bearing iron slag with silica, flux, and a carbon reductant followed by refinement by vanadium pentoxide. The reaction takes place in a submerged electric arc furnace yielding a ferrovanadium alloy containing about 40 wt % vanadium, 3.5 wt % silicon, 3.8 wt % manganese, 0.1 wt % carbon, and the remainder iron.

Economic Factors

Prices.—Time-price relationships for vanadium contained in fused vanadium pentoxide (metallurgical grade) in terms of actual prices and in constant 1989 dollars are shown in table 3. Beginning in 1974, published quotes of fused vanadium pentoxide reflect a two-tier price listing of upper and lower producer prices. Actual prices reported in table 3 were based on available information from the producer, or they represent averages of the two-tier quotation as reported in the time period indicated.

Tariffs.—U.S. import duties on selected vanadium items as of January 1, 1989, are listed in table 8. The tariff listing includes rates for both most-favored-nation (MFN) and non-most-favored-nation status.

[1] Metal Bulletin, No. 7425, Oct. 16, 1989.

[2] Briefing Paper. Vanadium Pentoxide Plant Fort McMurry, Alberta. Carbovan Inc., 2200 Mississauga, Ontario, Canada.

[3] American Metal Market. Pacific to Refine, Sell Vanadium Starting in '91. V. 97, No. 92, May 11, 1989.

[4] Mining Journal (London). Chinese Vanadium Output. V. 313, No. 8047, Nov. 24, 1989, p. 424.

[5] South Africa's Minerals Industry 1988, Republic of South Africa, Department of Mineral and Energy Affairs, Minerals Bureau, p. 129.

[6] The Text Report. V. 21, No. 4892, Apr. 11, 1989, p. 3.

[7] American Society for Testing and Materials. Standard Specifications for Ferrovanadium. A 102-76 in 1980 annual Book of ASTM Standards: Part 2, Ferrous Castings; Ferroalloys. Philadelphia PA, 1980, pp. 88-90.

[8] Renov, A. B., and A. A. Yaroshevsky. Earth's Crust Geochemistry. Sec. in The Encyclopedia of Geochemistry and Environmental Sciences, ed. by R. W. Fairbridge. Van Nostrand Reinhold, 1972, pp. 243-254.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Vanadium. Ch. in Mineral Commodity Summaries.

Vanadium. Reported monthly in Mineral Industry Surveys.

Other Sources

Chemical and Engineering News.
Engineering and Mining Journal.
Metal Bulletin Monthly (London).
Metal Price Support (London).
Metalworking News.
Roskill Reports (London).
The Mining Record.

TABLE 9

U.S. EXPORTS OF VANADIUM IN 1989, BY COUNTRY

(Thousand pounds and thousand dollars)

Country	Ferrovanadium (gross weight)		Vanadium ore and concentrate (vanadium content)		Vanadium compounds (gross weight)			
					Pentoxide (anhydride)[1]		Other[2]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Argentina	—	—	—	—	86	295	—	—
Australia	—	—	—	—	1	5	90	34
Austria	—	—	—	—	87	445	375	1,519
Barbadoes	—	—	—	—	—	—	—	—
Belgium-Luxembourg	—	—	—	—	2,683	11,623	1,791	548
Brazil	—	—	—	—	954	4,038	117	33
Canada	959	4,148	—	—	2	329	140	105
Chile	—	—	—	—	(3)	9	23	39
China	—	—	—	—	—	—	—	—
Colombia	—	—	—	—	—	—	85	43
Egypt	—	—	—	—	—	—	77	23
Finland	—	—	—	—	—	—	—	—
France	10	49	—	—	—	—	5	28
German Democratic Republic	—	—	—	—	734	4,069	—	—
Germany, Federal Republic of	—	—	—	—	931	2,870	20	150
Honduras	—	—	—	—	10	16	—	—
Hong Kong	—	—	—	—	307	1,548	—	—
India	—	—	—	—	—	—	128	245
Israel	—	—	—	—	—	—	—	—
Italy	—	—	—	—	—	—	1	8
Jamaica	—	—	—	—	—	—	2	19
Japan	—	—	—	—	129	350	(3)	9
Korea, Republic of	—	—	—	—	—	—	237	209
Malaysia	7	29	—	—	—	—	—	—
Mexico	10	60	—	—	305	1,425	81	95
Netherlands	—	—	—	—	550	3,069	—	—
Nigeria	—	—	—	—	7	62	—	—
Norway	—	—	—	—	—	—	—	—
Pakistan	—	—	—	—	11	51	—	—
Peru	—	—	—	—	11	8	—	—
Philippines	—	—	—	—	—	—	69	36
Portugal	—	—	—	—	—	—	—	—
Singapore	—	—	—	—	—	—	—	—
Spain	—	—	—	—	—	—	—	—
Sweden	—	—	—	—	482	2,342	150	989
Taiwan	14	60	—	—	1	5	—	—
Thailand	—	—	—	—	—	—	8	82
United Kingdom	2	16	—	—	952	2,635	21	49
Venezuela	88	937	—	—	3	11	—	—
Zimbabwe	—	—	—	—	—	—	—	—
Total[4]	1,087	5,299	—	—	8,248	35,205	3,418	4,262

[1] May include catalysts containing vanadium pentoxide.
[2] Excludes vanadates.
[3] Less than 1/2 unit.
[4] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 10

U.S. IMPORTS OF FERROVANADIUM, BY COUNTRY

(Thousand pounds and thousand dollars)

Country	1988			1989		
	Gross weight	Vanadium content	Value	Gross weight	Vanadium content	Value
General imports:						
Austria	112	92	631	267	218	3,283
Belgium-Luxembourg	86	69	839	149	122	1,625
Brazil	—	—	—	38	27	364
Canada	88	71	730	401	327	5,142
France	—	—	—	2	2	17
Germany, Federal Republic of	10	6	70	415	256	2,631
Japan	—	—	—	154	124	259
Mexico	—	—	—	7	6	10
Total[1]	296	238	2,271	1,433	1,080	13,331
Imports for consumption:						
Austria	112	92	631	267	218	3,283
Belgium-Luxembourg	86	69	839	160	130	1,786
Brazil	—	—	—	38	27	364
Canada	88	71	730	401	327	5,142
France	—	—	—	2	2	17
Germany, Federal Republic of	10	6	70	415	256	2,631
Japan	—	—	—	134	108	259
Mexico	—	—	—	7	6	10
Total[1]	296	238	2,271	1,424	1,073	13,493

[1] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 11

U.S. IMPORTS OF VANADIUM PENTOXIDE (ANHYDRIDE), BY COUNTRY

Country	1988			1989		
	Gross weight (pounds)	Vanadium content (pounds)	Value	Gross weight pounds)	Vanadium content (pounds)	Value
General imports:						
Canada	—	—	—	1,091	624	$4,076
China	703,936	394,321	$2,230,293	70,548	69,589	564,801
France	700	392	24,265	—	—	—
Germany, Federal Republic of	550	308	2,084	3,823	2,284	47,988
South Africa, Republic of	799,506	447,856	2,724,431	332,997	221,198	2,249,826
United Kingdom	—	—	—	1,034	593	6,586
Total[1]	1,504,692	842,877	4,981,073	409,493	294,288	2,873,277
Imports for consumption:						
Canada	—	—	—	1,091	624	4,076
China	169,836	95,136	502,923	—	—	—
France	700	392	24,265	—	—	—
Germany, Federal Republic of	550	308	2,084	3,823	2,284	47,988
South Africa, Republic of	689,981	386,504	2,419,680	295,587	199,822	1,851,913
United Kingdom	—	—	—	1,034	593	6,586
Total[1]	861,067	482,340	2,948,952	301,535	203,323	1,910,563

[1] Data may not add to totals shown because of independent rounding.

TABLE 12

VANADIUM: WORLD PRODUCTION, BY COUNTRY[1]

(Short tons of contained vanadium)

Country	1985	1986	1987	1988[p]	1989[e]
Production from ores, concentrates, slag:[2]					
China (vanadiferous slag product)[e]	5,000	5,000	5,000	5,000	5,000
Finland (in vanadium pentoxide product)	2,350	—	—	—	—
South Africa, Republic of:[3]					
Content of pentoxide and vanadate products[e]	6,537	6,350	4,580	5,600	5,735
Content of vanadiferous slag product[e 4]	8,912	10,580	11,135	12,460	12,465
Total	15,449	16,930	15,715	18,060	18,200
U.S.S.R.[e]	10,500	10,600	10,600	10,600	10,600
United States (recoverable vanadium)	W	W	W	W	W
Total[5]	33,299	32,530	31,315	33,660	33,800
Production from petroleum residues, ash, spent catalysts:[6]					
Japan (in vanadium pentoxide product)[e]	840	[7]929	925	925	925
United States (in vanadium pentoxide and ferrovanadium products)	2,695	2,330	2,508	3,252	[7]2,633
Total	3,535	3,259	3,433	4,177	3,558
Grand total	36,834	35,789	34,748	37,837	37,358

[e] Estimated. [p] Preliminary. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1] In addition to the countries listed, vanadium in also recovered from petroleum residues in the Federal Republic of Germany, the U.S.S.R., and several other European countries, but available information is insufficient to make reliable estimates. Table includes data available through June 29, 1990.

[2] Production in this section is credited to the country that was the origin of the vanadiferous raw material.

[3] Includes production for Bophuthatswana.

[4] Data on vanadium content of vanadium slag are estimated on the basis of a reported tonnage of vanadium-bearing slag (gross weight) multiplied by an assumed grade of 14.1% vanadium.

[5] Excludes U.S. production.

[6] Production in this section credited to the country where the vanadiferous product is extracted; available information is inadequate to permit crediting this output back to the country of origin of the vanadiferous raw material.

[7] Reported figure.

TABLE 13

VANADIUM: WORLD PROCESSING FACILITIES

Country and plant	Location	Vanadium processing[1]				
		Vanadium pentoxide	Ferro-vanadium	Ammonium metavanadate	Vanadium-aluminum alloy	Other[2]
United States:						
AMAX Metals Recovery Corp.	Braithwaite, LA	x	—	—	—	—
Cotter Corp.	Canon City, CO	x	—	—	—	—
Gulf Chemical & Metallurgical Corp.	Freeport, TX	x	—	—	—	—
Kerr-McGee Chemical Corp.	Soda Springs, ID	x	—	x	—	—
Reading Alloys, Inc.	Robesonia, PA	—	—	—	x	C
Shieldalloy Metallurgical Corp.	Cambridge, OH	—	x	x	x	B,E
U.S. Vanadium Corp.	Hot Springs, AR	x	—	—	—	—
Do.	Niagara Falls, NY	—	x	—	x	A,E
Teledyne Wah Chang	Albany, OR	—	—	—	—	C,D
Umetco Minerals Corp.	Blanding, UT	x	—	—	—	—
Akzo Chemical Co.	Weston, MI	—	—	—	—	E
Canada:						
Masterloy Products Ltd.	Gloucester, Ontario	—	x	—	—	—
Carbovan Inc.	Fort McMurray, Saskatchewan	x	—	—	—	—
Germany, Federal Republic of:						
Gesellschaft fur Electrometallurgie mbH	Nuremburg	—	x	—	x	—
Belgium:						
Sadacem (Langerbruggekaai Plant)	Kent	—	x	—	—	—
Spain:						
Ferroastur SA	Poligono de Maqua, Aviles	—	x	—	—	—
Sweden:						
Metals & Powders Trollhatten AB (Sandvik AB)	Trollhatten	—	x	—	—	—
United Kingdom:						
Murex Ltd.	Rainham, Essex	x	x	x	—	—
London & Scandinavian Metallurgical Co. Ltd.	Rotherham, S. Yorkshire	—	x	—	—	—
Ferroalloys & Metals Ltd.	Glossop, Derbyshire	—	x	—	—	—
South Africa, Republic of:						
Highveld Steel & Vanadium Corp.	Witbank	x	—	x	—	—
Vansa Vanadium SA Ltd.	Steelpoort, Eastern Transvaal	x	—	—	—	—
Vametco Minerals Corp.	Bushveld Complex	x	—	x	—	A
Transvaal Alloys Pty. Ltd.	Roos Senekal, Transvaal	x	—	—	—	—
Union Steel Corp.	Vereeniging	x	—	—	—	—
Japan:						
Awamura Metals Industry Co.	Uji, Kyoto	—	x	—	—	—
Taiyo Mining & Industrial Co.	Ako, —	—	x	—	—	—
Nippon Denko KK	Toyama	—	x	—	—	—
Japan Metals and Chemical Co.	Oguni, Yamagata	—	x	—	—	—
China:						
Chengde Plant	Hebei	x		—	—	—
Emei Ferroalloy Plant	Sichuan	—	x	—	—	—
China Titanium Plant	Zunyi, Guizhou	x	—	—	—	—
Jinzhou Ferroalloy Plant	Liaoning	x	x	—	—	—
Nanjing Ferroalloy Plant	Jiangsu	x	x	—	—	—
Shanghai Plant	Shanghai	—	x	—	—	—

See footnotes at end of table.

TABLE 13—Continued

VANADIUM: WORLD PROCESSING FACILITIES

Country and plant	Location	Vanadium processing[1]				
		Vanadium pentoxide	Ferro-vanadium	Ammonium metavanadate	Vanadium-aluminum alloy	Other[2]
U.S.S.R.:						
Chusovskoy Met. Savod	Chusovoy	x	x	—	—	—
Novo-Tagilskiy Met. Zavod	Nizhniy-Tagil	x	x	—	—	—
Novo-Tulskiy Met. Zavod	Tula	x	x	—	—	—
Serovskiy Met. Zavod	Serov	x	x	—	—	—

[1] x, Producer; —nonproducer.

[2] A, Nitrovan, proprietary product; B, Ferovan, proprietary product; C, Vanadium metal producer; D, Vanadium-zirconium alloy producer; E, Unsupported vanadium catalyst producer.